Application of Temperature Swing Adsorption for Gas Dehydration

1. Background

Water vapor is one of the most common and destructive impurities present in industrial gases such as compressed air, natural gas, and shale gas. Condensed water can accumulate in gas pipelines and corrode the inner walls. If the pipeline is exposed to cold temperatures, the trapped water will freeze and expand, further weakening the pipe material. Accumulation of these effects may even cause the pipe system to rupture. Therefore, there is great need for commercial and geological gases to be dried and dehydrated before use.

Natural gas, as one of the cleanest fossil fuels, plays an important role in providing energy for industry and daily life. However, natural gas also contains a certain amount of water when extracted from the ground. Shale gas, with its huge reserves, has become an important part of the world's energy supply. However, the original shale gas contains water and other components which complicates processing and transportation. Dehydration is an important process and equipment for removing water from shale gas to prevent corrosion and blockage of pipelines and heat exchangers.[(1)]

Solid adsorbents are widely used for gas dehumidification. These materials typically have large specific surface areas and rich pore structures, allowing the water molecules to aggregate on the surface of the adsorbents and in the pores. Traditional materials include molecular sieves, silica gel, and alumina,[(2)] while recent studies have explored MOFs and COFs for water adsorption.[(3,4)] One of the most effective methods for vapor removal is temperature swing adsorption (TSA), which consists of vapor adsorption and adsorbent regeneration cycles. This article mainly focuses on the application of TSA and TSA technology in the drying of compressed air, shale gas, and natural gas for moisture removal.

2. Temperature Swing Adsorption (TSA)

2.1 Adsorption Separation Theory

Adsorption separation converts a multicomponent mixture into two or more components by passing them through an adsorbent. Adsorption separation generally involves two categories of applications:

- ✓ Gas separation: Adsorbate makes up more than 10% w/w of the feed gas
- ✓ Gas purification: Adsorbate makes up less than 10% w/w (typically less than 2%) of the feed gas

The adsorption separation process is usually carried out in regeneration cycles. The regeneration methods of the adsorbent include:

- ✓ Heating: Increase temperature to decrease adsorption capacity

- ✓ Inert cleaning: Flow non-adsorbing gas to dilute concentration of adsorbate and facilitate desorbtion
- ✓ Swapping: Introduce more easily adsorbed adsorbate to displace original adsorbate
- ✓ Pressure variation: Decrease pressure to remove adsorbates

When choosing the desorption method, several methods are usually combined. In the application of raw gas drying, heating and inert cleaning methods are often combined simultaneously, which is called **temperature swing adsorption (TSA)**. The TSA method regenerates the adsorbent by introducing high-temperature regeneration gas into the bed layer, removing adsorbates. The TSA method is generally applicable to gas purification, such as drying of compressed air, shale gas, and natural gas.

2.2 The Principles of TSA Cycling

The gas drying process based on the TSA cycle typically uses fixed-bed adsorption towers. At least two adsorption towers are set up simultaneously in the process to ensure continuous purification. The most commonly used system is the dual tower system, shown in Figure 1, where one tower is performing adsorption while the other is undergoing regeneration, alternating in a cycle.

During the adsorption process, raw gas is introduced into the feed end of the adsorption bed. After the adsorbent selectively adsorbs the moisture in the raw gas, the dried product gas is obtained from the product end of the adsorption bed. The adsorbents are usually activated alumina and 13X molecular sieves. Due to the decrease in adsorption capacity with the increase in temperature, the adsorption process is carried out at room temperature to ensure the adsorption capacity of the adsorbents.

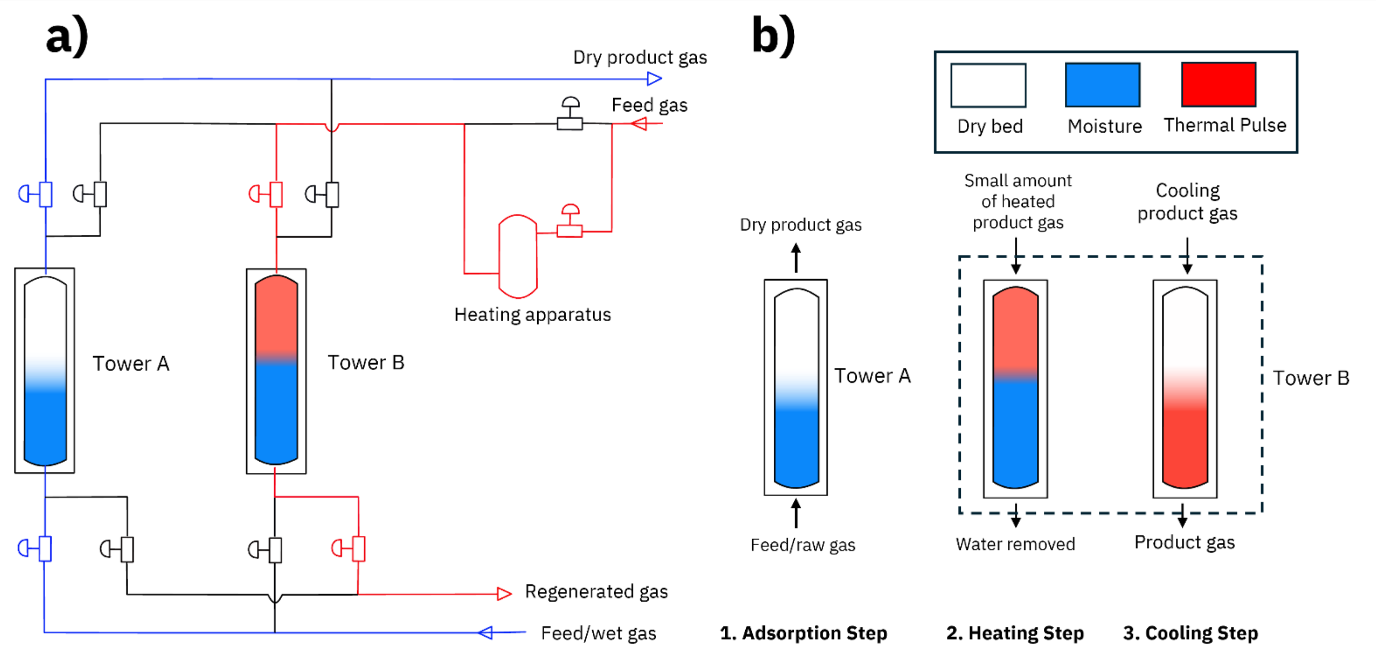

Figure 1: a) TSA circulation system flowchart, b) TSA working principle

When the adsorption process is completed, based on the water content distribution, the adsorption bed layer is divided into three zones (see Figure 2).

Zone 1: Saturated bed zone (SBZ)

- ✓ Closest to the gas inlet
- ✓ Water content in the bed layer is close to that of the raw gas
- ✓ Adsorption capacity of the bed layer is close to saturation

Zone 2: Mass transfer zone (MTZ)

- ✓ Area in between SBZ and UBZ
- ✓ Water content begins to continuously decrease along the adsorbent bed to form an S-shaped concentration curve

Zone 3: Unused bed zone (UBZ)

- ✓ Adsorbent never comes into contact with water because it has all been adsorbed in the MTZ

Once all of the water vapor is adsorbed (reaching UBZ), the tower then proceeds with adsorbate regeneration. The regeneration process mainly consists of two steps: heating and cooling. In the heating step, the adsorbent is heated to desorb the water it has adsorbed. In the cooling step, the adsorbent is cooled to restore its adsorption capacity. These steps are achieved by introducing regeneration gas of different temperatures into the adsorption bed. The regeneration gas is

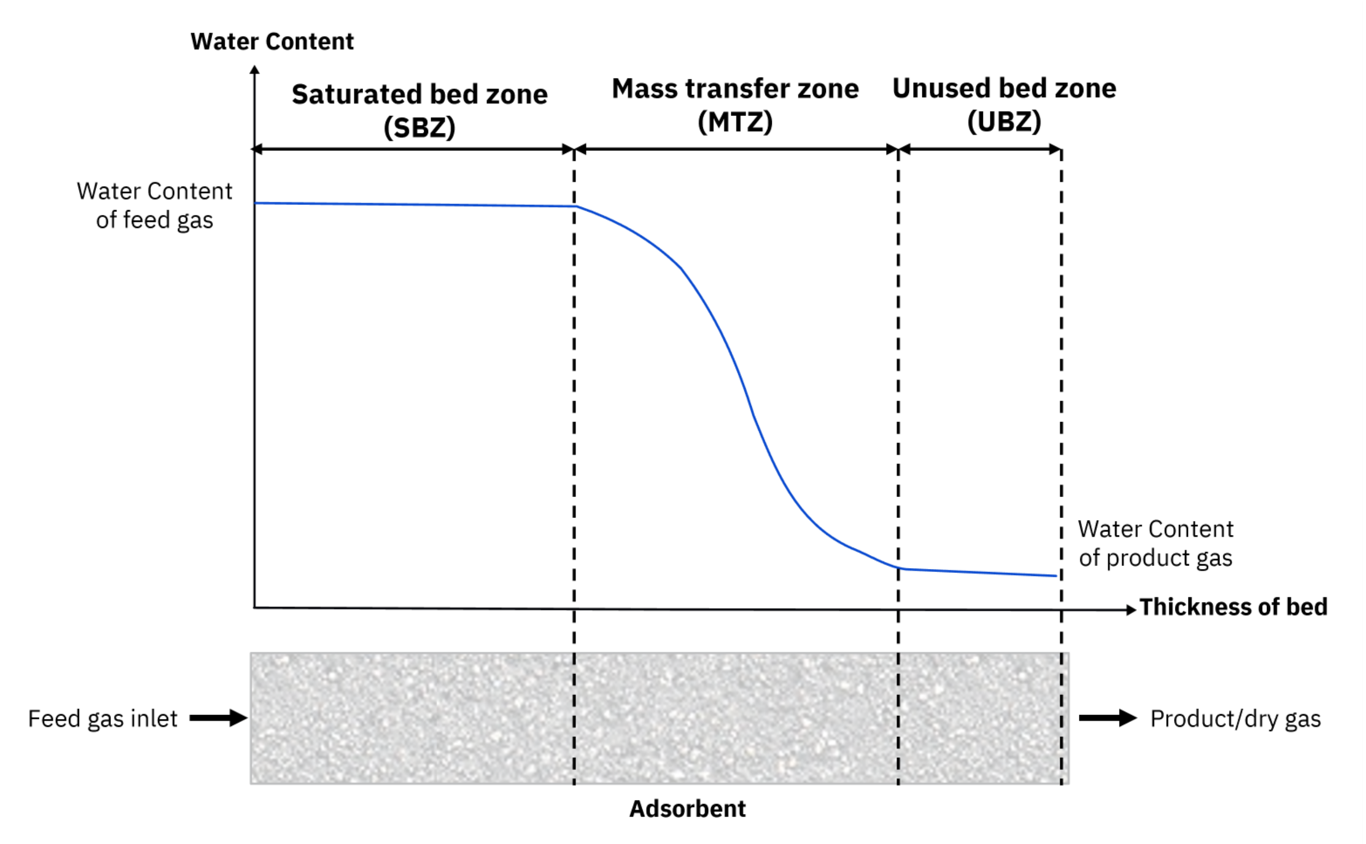

Figure 2: Distribution of water content in the adsorption bed

introduced into the product end of the adsorption bed in the opposite direction of the raw gas flow direction; the regeneration gas is usually dry product gas.

2.3 The Three-Tower Process

In actual engineering applications, large quantities of gas may be need to be dehumidified. However, the efficiency of the two-tower process is relatively low at large scales. Therefore, a three-tower process or a multi-tower process can be adopted, as shown in Figure 6. In the three-tower process, there are two ways of operation. One is that two towers perform adsorption operations simultaneously, while the third tower is used for regeneration and cooling. For example, towers A and B perform adsorption work, and then after 8 hours, towers B and C perform adsorption work, followed by 8 hours later, towers C and A perform adsorption work, and so on, in a cycle. This solution is mostly applied in working conditions where the regeneration time is short and the moisture content of the feed gas is low. The other method is that one tower performs adsorption, one tower is heated, and another tower performs cooling operations. This solution is mostly applied in working conditions where the cycle period is short or where both carbon ions and water vapor need to be removed simultaneously. The regeneration process involves heating the regeneration gas to a certain temperature and then introducing it into the adsorption tower to remove the adsorbed moisture. The overall process can be summarized as low-temperature adsorption in Tower A, high-temperature desorption in Tower B, and regeneration in Tower C.

BTSorb 100 Series

- ✓ Cost-effective, compact dynamic physisorption analyzer for breakthrough and adsorption studies
- ✓ Ideal for small scale TSA experiments
- ✓ TSA temperature control model allows for TSA up to 400 °C
- ✓ Easily switch between pretreatment and experimental steps

Figure 3: Highlights of the ***BTSorb 100*** *Series from* ***AMI***

3. AMI Solutions for TSA

AMI offers several customizable solutions for temperature swing adsorption. For small scale applications, the **BTSorb 100**, shown in Figure 3, offers reliable physisorption data with temperature capabilities up to 400 °C. For larger scale experiments, **AMI** offers a wide range of fully customizable reactor systems, including the **Three-Tube Series Adsorption Breakthrough Reactor**. This versatile system can be configured for a two-tower or three-tower TSA system.

Three-Tube Series Adsorption Breakthrough Reactor

- ✓ Designed to simulate breakthrough behavior of multi-component gases in adsorbent materials
- ✓ Widely applicable and customizable for different physisorption techniques including TSA and PSA
- ✓ Triple tube design allows for either two-tower or three-tower TSA experiments

Figure 4 : Highlights of the ***Three-Tube Series Adsorption Breakthrough Reactor*** *from* ***AMI***

4. Conclusions

Shale gas and natural gas are regarded as important clean energy sources. They are indispensable resources in the industrialization process. Both contain a certain amount of moisture. The presence of saturated water will increase the pressure drop of gas flow, reduce the transportation capacity of gas pipelines, and increase the transportation cost. Secondly, under the action of high pressure or low temperature, saturated water will precipitate from the gas flow and become liquid water, causing corrosion and reducing the service life of pipelines. Therefore, when utilizing these resources, it is necessary to remove water first. The TSA method utilizes the physical effect of low-temperature adsorption and high-temperature desorption of adsorbents to effectively remove moisture. The TSA method also has a small consumption of regeneration gas (which comes from the raw gas), low comprehensive energy consumption, and is widely used in gas purification.

5. References

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